

A Comparison Between Planar and Nonplanar Free-Flight Data

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Results from the first program designed to explore the difference between the planar and nonplanar dynamic stability coefficient, using the JPL developed bi-planar wind-tunnel free-flight system, are presented. Two widely different configurations, a blunt 60-deg half-angle cone and a sharp 10-deg half-angle cone were tested. The overall accuracy of the data was extremely high and firmly demonstrates the capability of the technique. Although no dramatic difference in the coefficients was apparent from the data, which was limited in number, they do suggest that there is a favorable increase in the coefficient as the motion becomes more nonplanar.

Introduction

Predicting the angle-of-attack history of a body exhibiting nonplanar motion from planar data can be erroneous since it presupposes that there are no aerodynamic coupling forces and further requires that the conventional aerodynamic forces which are observable in the planar mode are the same in the nonplanar mode. The investigation of this last requirement was the main purpose of an experimental program conducted in the JPL Supersonic Wind Tunnel using a refined nonplanar free-flight system. Specifically, the program was directed toward the question of whether the dynamic stability coefficient is different in the two modes. For this investigation two widely different configurations were chosen: a short, blunt 60-deg half-angle cone and a sharp 10-deg half-angle cone. This article presents the results of this test program.

Test Operation

The basis of the testing technique is to launch models upstream into the oncoming flow with a pneumatic gun (Reference 1). In the case of nonplanar flight, the models are released with an initial angle of attack, yaw angular velocity, and spin rate. The proper combination of these three initial conditions will produce any desired nonplanar motion. The

motion is recorded with a high-speed 35-mm movie camera operating at about 2000 frames per second. Two views of the model in flight are obtained by splitting the schlieren strobe light and directing the two beam halves through the test section, 60 deg apart, by means of a complex mirror system (References 2 and 3). Generally, about 250 frames of data are obtained for a flight. Each pair of angles from a frame set is measured and mathematically transformed to a vertical and horizontal set. Nominal accuracies are 0.2 deg for the slender models and 0.5 deg for the blunt bodies. In addition to this data, an independent measurement of the model's spin rate is obtained by means of either a fiber optics lens system mounted inside the tunnel, which transmits a picture of the model's base to an outside camera, or a stripe painted on the model.

The data is processed in a manner similar to the procedure used in a ballistic range, which is to numerically fit the angle data with the tricyclic equation of motion (Reference 4). From this fit the static stability coefficient (C_{m_α}), the dynamic stability coefficient ($C_{m_q} + C_{m_\alpha}$), and the magnus moment coefficient ($C_{m_{p_\alpha}}$) are obtained. The drag coefficient (C_D) is independently obtained from the model's translational history.

The 60-deg blunt body test was conducted principally at Mach 3.97 with a few shots at Mach 1.65. The 10-deg cone test was performed at Mach 4.56. The diameters of the blunt models and of the sharp cones were 3.81 and 2.54 cm (1.5 and 1.0 in.), respectively. The models were designed to optimize the number of pitch cycles and angle-of-attack decay during a flight. This is accomplished by constructing them with a dense core and a light plastic exterior shell; in the case of the blunt cones, gold was used for the cores. Typical weights for the models were 28 g for the 60-deg cones and 10 g for the 10-deg cones. The blunt cones were launched at spin rates varying from zero to 35 rev/s. The 10-deg cone spin rates were from 90 to 135 rev/s (resonance was about 60 rev/s).

A representative α - β plot (angle of attack versus angle of yaw) from both tests is shown in Figures 1 and 2 along with a frame of movie data from each flight. The stars are the raw data points obtained from the movie frames and the smooth curves are from the fit equations. The standard rms angle-of-attack deviations were about 0.4 deg for the 10-deg cone flights and 0.9 deg for the blunt body flights.

Test Results

Before proceeding to the dynamic stability data, it is wise to first investigate the drag and static stability results since they provide a gauge as to the quality of the data. The drag and static stability coefficients are the results of first-order driving forces and can be obtained much more accurately than the dynamic stability coefficient which is the result of second-order forces. If the static data from a flight looks good, confidence in the value of the dynamic stability coefficient is increased.

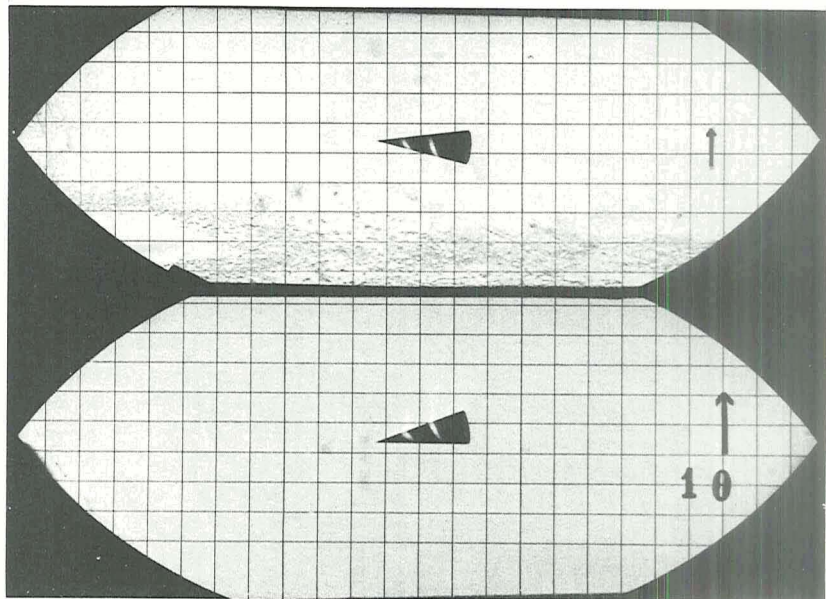
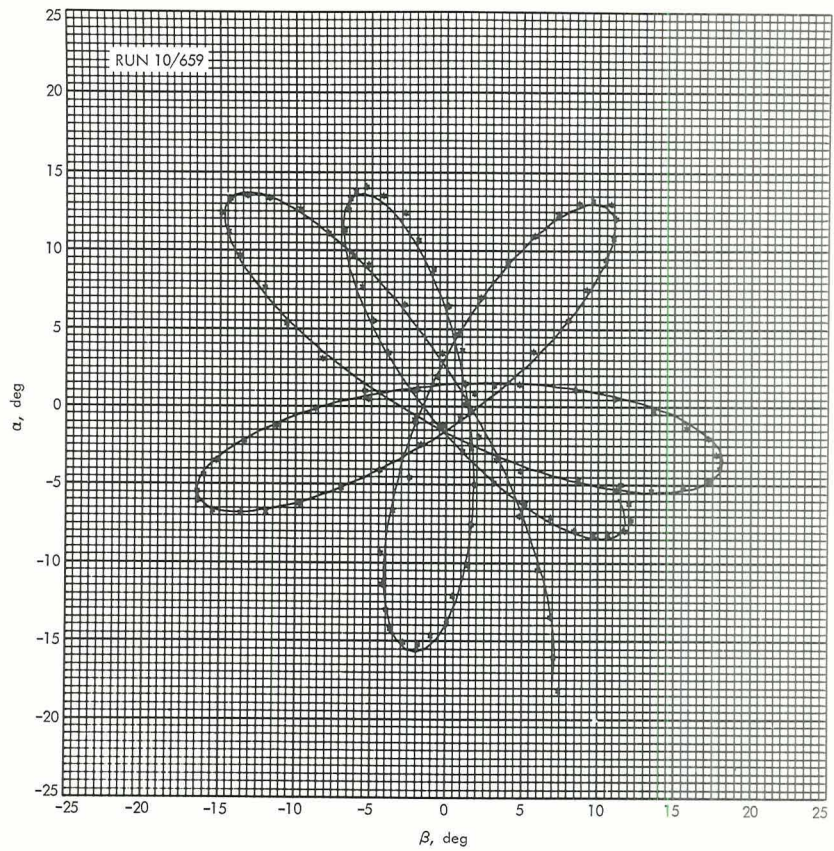


Figure 1. Representative 10-deg cone data

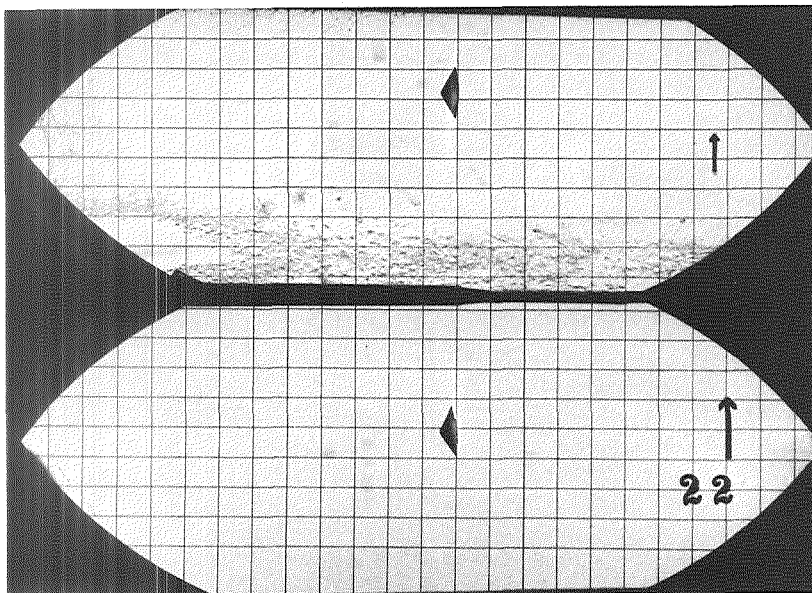
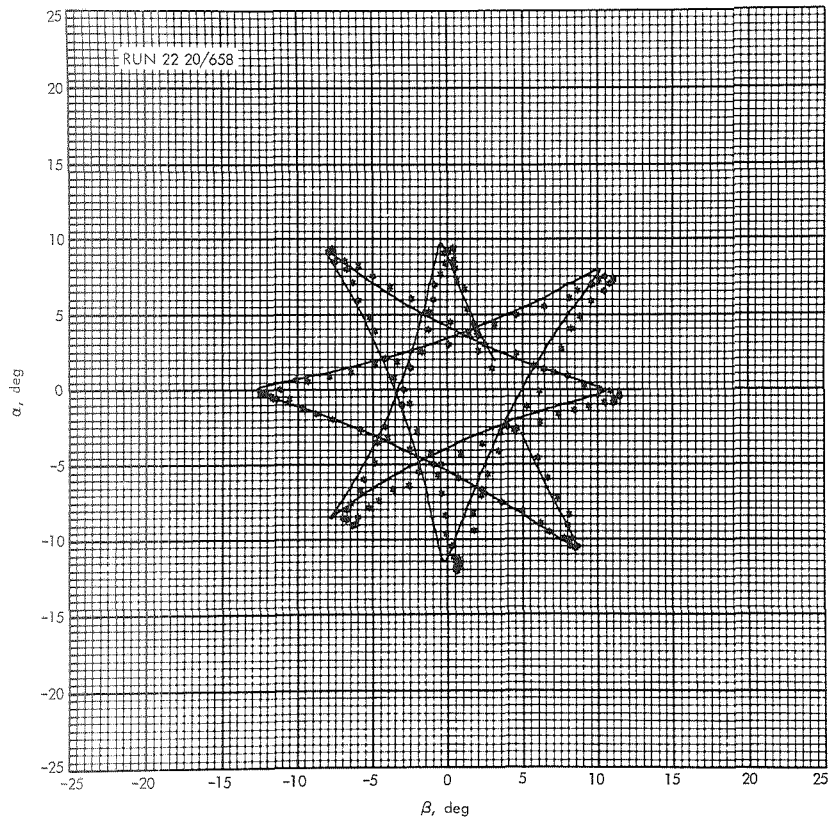


Figure 2. Representative 60-deg blunt body data

The drag and stability data are best correlated with the mean-square resultant angle of attack, δ^2 , which is defined as

$$\delta^2 = \frac{\int_0^x (\eta^2) dx}{x}$$

where η is the resultant angle of attack and x is the relative distance between the model and free-stream. It has been shown that if a body has local drag coefficient of the form $C_D = C_{D_0} + k\eta^2$, then the effective drag coefficient is $C_{D_{\text{eff}}} = C_{D_0} + k\delta^2$. Figure 3 contains the effective drag data from both tests. The data consistency for both configurations is excellent, particularly the 10-deg cone where the deviation is less than 0.25%. The data also exhibit straight-line correlations with δ^2 , which means that the drag coefficients for both configurations are quadratic functions of the angle of attack.

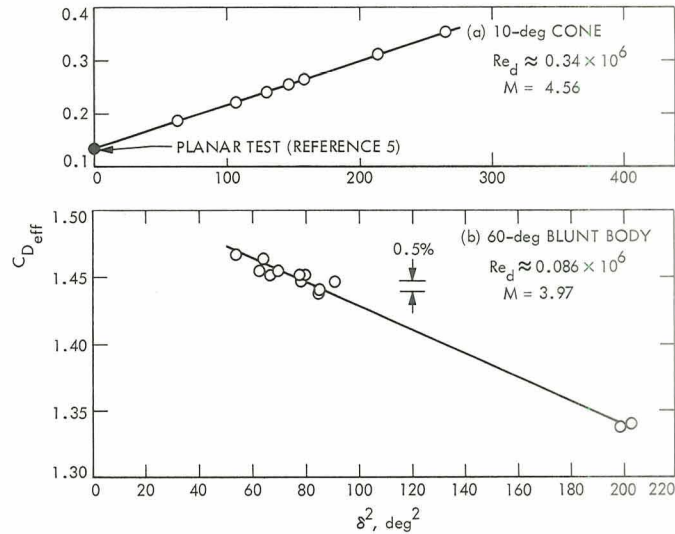


Figure 3. Drag results

Figure 4 contains the static stability data from both tests as a function of δ^2 . The 10-deg cone data does not vary with δ^2 , indicating that the pitching moment is dependent upon the angle of attack (at least through the region tested). The data deviation from the mean is excellent, less than 0.5%. The blunt body data shows a large increase in the static stability coefficient at large δ^2 's, indicating a highly nonlinear pitching moment. From an examination of the flights themselves, it appears that the coefficients are more accurate than the scatter on the plot would indicate. Part of the problem is due to the use of δ^2 as the correlator since it is not necessarily the proper one for a nonlinear pitching moment. A vehicle experiencing the same δ^2 during both planar and circular flights

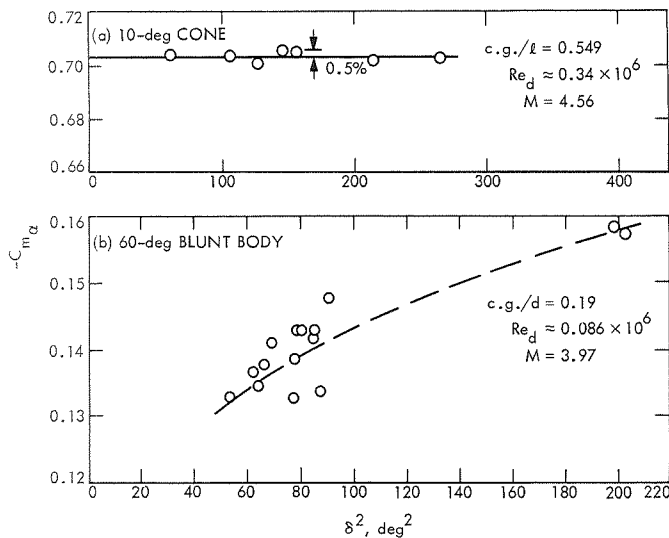


Figure 4. Static stability results

will not necessarily have the same effective static stability coefficients for both of them. This has been demonstrated for the case of a cubic pitching moment ($C_m = C\alpha + k\alpha^3$), where the appropriate correlator for an arbitrary nonplanar flight is a much more complicated function than δ^2 (Reference 4). Another factor that might relate to the scatter of the data is the "phase difference"; i.e., there appears to be a difference between the time the amplitude nodes generated by the fit equation occur and those formed by the raw data occur. (See Run 22, Figure 2, for an example.) After extensive study of this problem, it is now believed to be primarily the result of the combination of a highly nonlinear pitching moment and a trim angle due to an offset center of gravity (c. g.). Fortunately, both the correlator problem and the phase problem have a rather small influence on the values of the aerodynamic coefficients obtained from the data reduction, and although the scatter of the data is larger than it should be, it is still quite small. Nevertheless, efforts to reconcile the differences are continuing.

The dynamic stability data for both configurations are presented as a function of δ^2 in Figure 5 and as a function of roll rate to velocity ratio (p/V) in Figure 6. This last parameter relates to the degree to which the motion is nonplanar and is merely a first attempt to use a nonplanar correlation parameter. When presented as a function of δ^2 (Figure 5), particularly in the case of the blunt body, the data does not correlate well. However, presented as a function of p/V , the correlation for both configurations is substantially improved. Interestingly, both sets of data for two completely different configurations demonstrate the same trend of an increase in the dynamic stability (a more negative dynamic stability coefficient is favorable) as the roll rate is increased to a point, and then

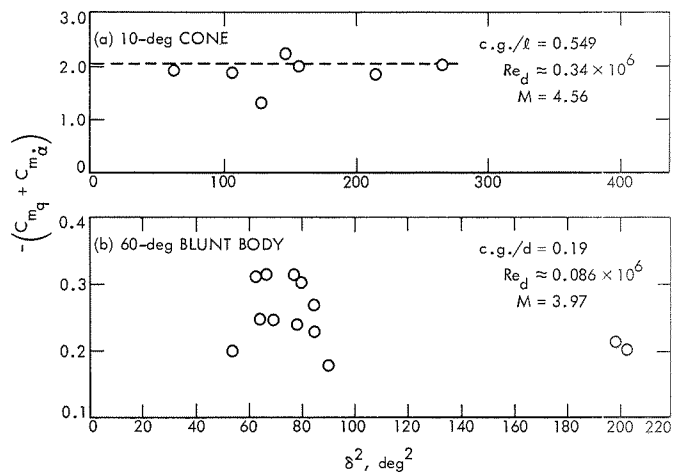


Figure 5. Dynamic stability data as a function of the mean-square resultant angle of attack

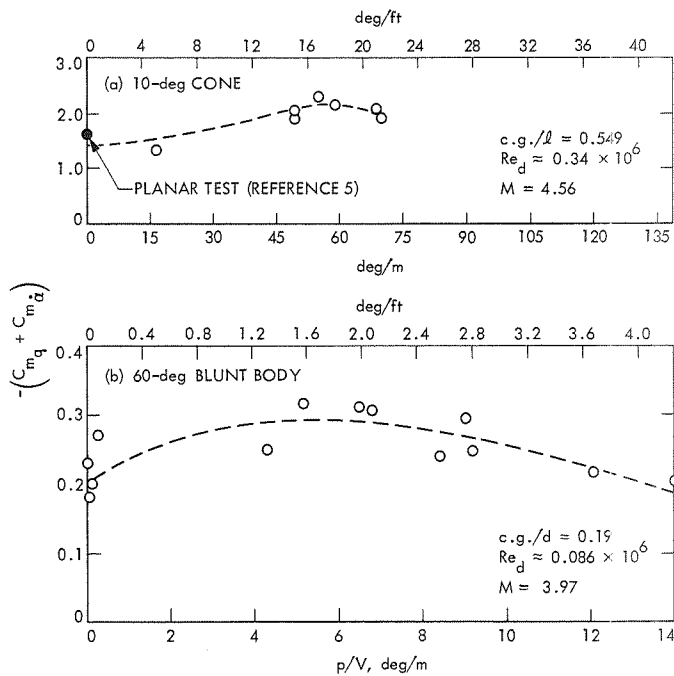


Figure 6. Dynamic stability data as a function of the roll to velocity ratio

a decrease in the dynamic stability. The fact that the dynamic stability coefficient changes with roll means that it is dependent upon the type of motion the body is undergoing, which is contrary to the traditional supposition that it is only dependent upon the angle of attack. It should be mentioned, however, that in order to investigate this subject thoroughly and obtain definitive conclusions much more data is required. More work oriented toward defining the key parameters, which determine dynamic stability, is needed.

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